Faster RooFitting

Automated Parallel Computation of Collaborative Statistical Models

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RooFit

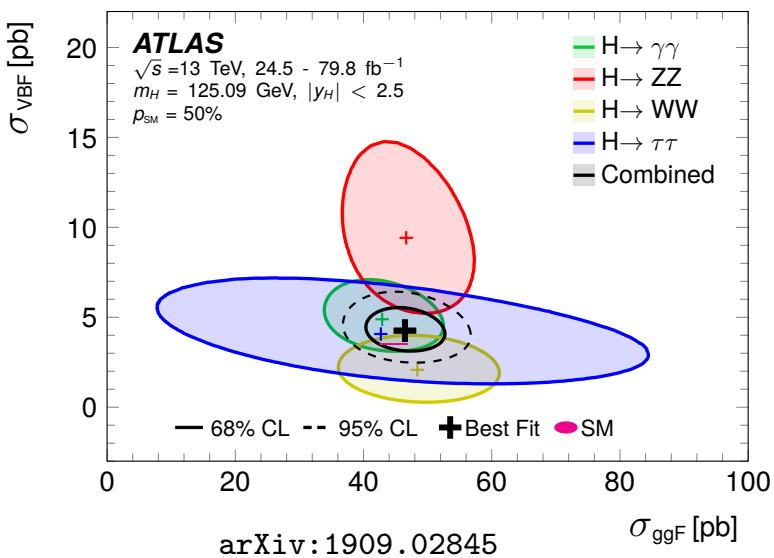
- `RooFit` is the statistical modeling & fitting package of `ROOT`
- used for statistical inference in many experiments
- extract parameters via Likelihood maximization
- separate model building & fitting from the technical implementation and **optimization**

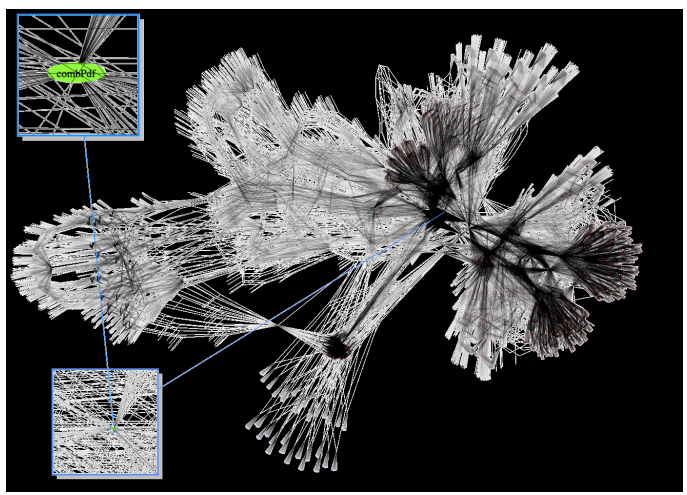
Parallelization

- `CPU` time dominated by repeated calculations of *-log L*
- `RooFit` internally parallelizes fitting
- user interface via `NumCPU(..)` argument

Collaborating & combining

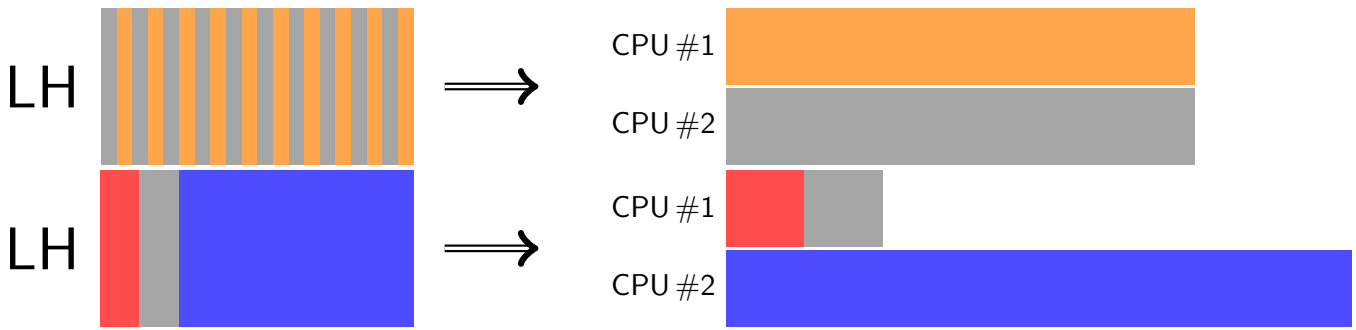
- central container object `RooWorkspace`
  - store models (p.d.f. modeling the data)
  - store datasets (binned or unbinned)
  - made persistent via `ROOT` streamer
- measurements can be easily combined by combining workspaces (both p.d.f and data)





RooFit: Existing Optimizations

- constant-term optimization/caching
- likelihood parallelization by event/bin



Faster RooFitting

- further parallelization (this project)
- vectorization of calculations (Stephan Hageböck)

Challenges

- Many components too small to efficiently distribute over many cores $\Rightarrow$ Relatively large overhead
- Other components very large (binned regions), not splitting efficiently over multiple workers

Solutions

1. Increase chunk sizes
2. Dynamic load balancing

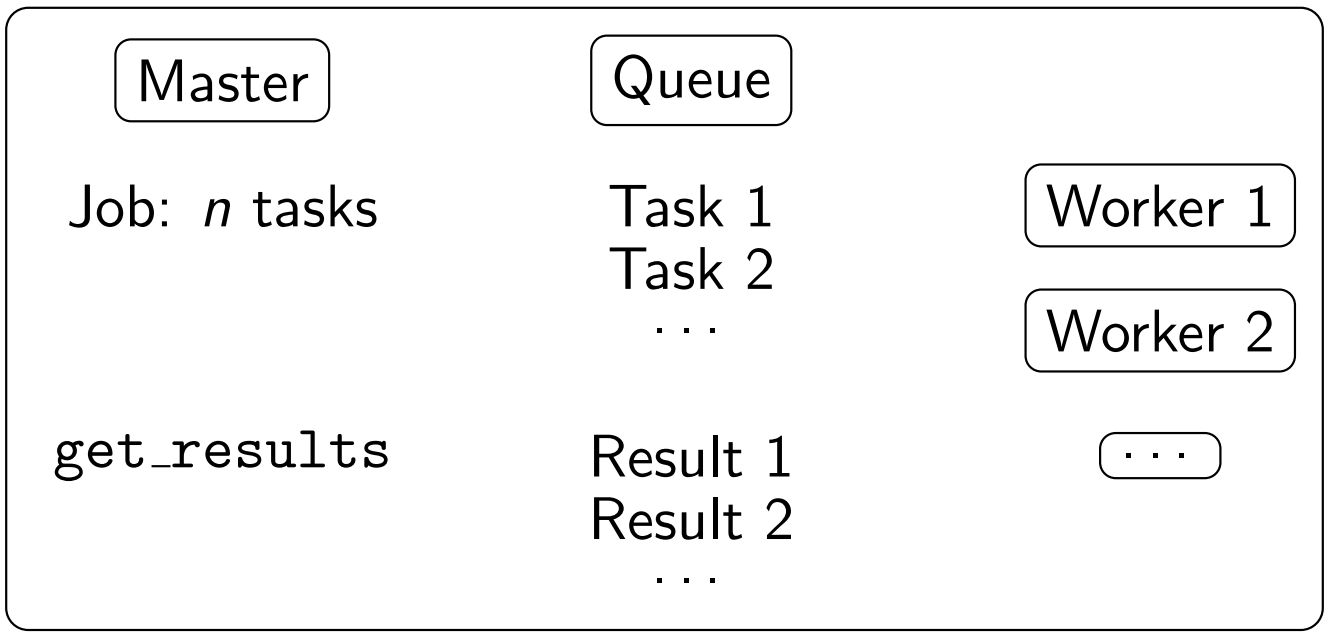
Solution 1: Partial derivatives

- Most CPU time spent in derivative calculations inside minimizer `MINUIT`
  - 1 Iteration $\sim$ Gradient + line-search
  - gradient for N parameters p: $\frac{df}{dp} \approx \frac{f(p-dp)-f(p)}{dp} \Rightarrow 2N$ calls of f
  - line-search: descend along gradient direction $\Rightarrow O(1)$ calls of f
- Focus on partial derivatives as *calculation chunk* instead of component likelihood
  - Required changes in `MINUIT`
  - made sure outputs stay exactly same

Solution 2: Dynamic Load Balancing

old custom `BidirMMapPipe` handles `fork`, `mmap`, pipes

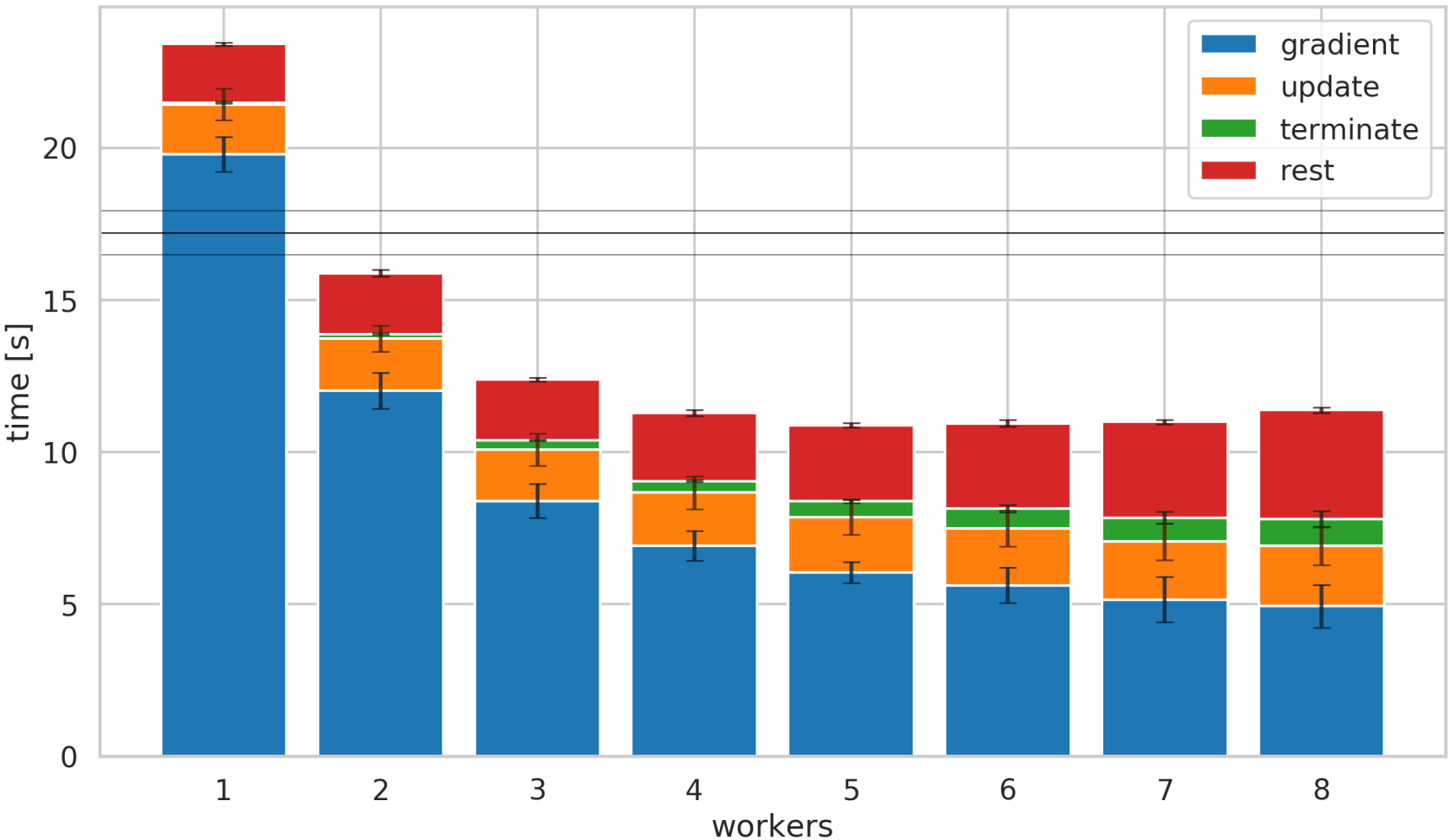
new ∅MQ for communication between forks



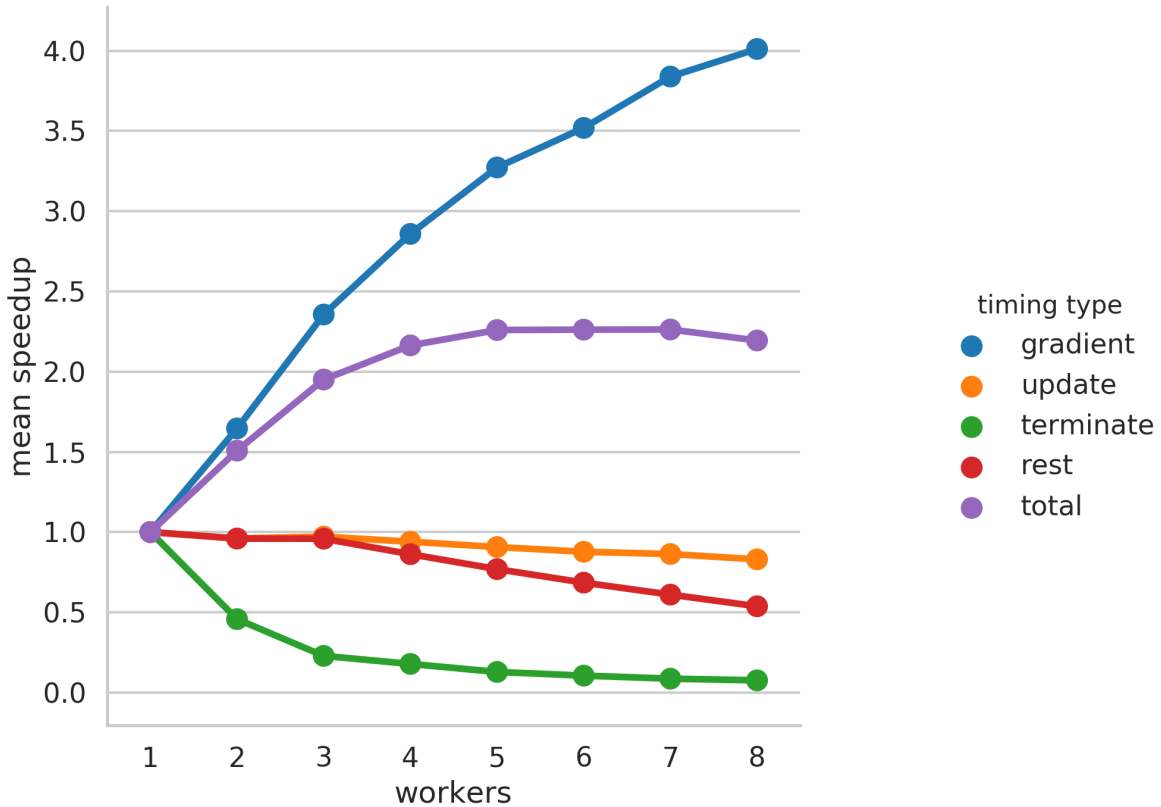
Benchmarks for MIGRAD fit / minimization

label	fast	big
model	ATLAS $H \to WW$ fit	ATLAS Higgs combination Moriond 2019
components	13795	126883
parameters	265	1487
approx. timing	20 s	10 min – few hours
comment	not main target audience, but used for fast benchmarking	depending on starting point

Small model

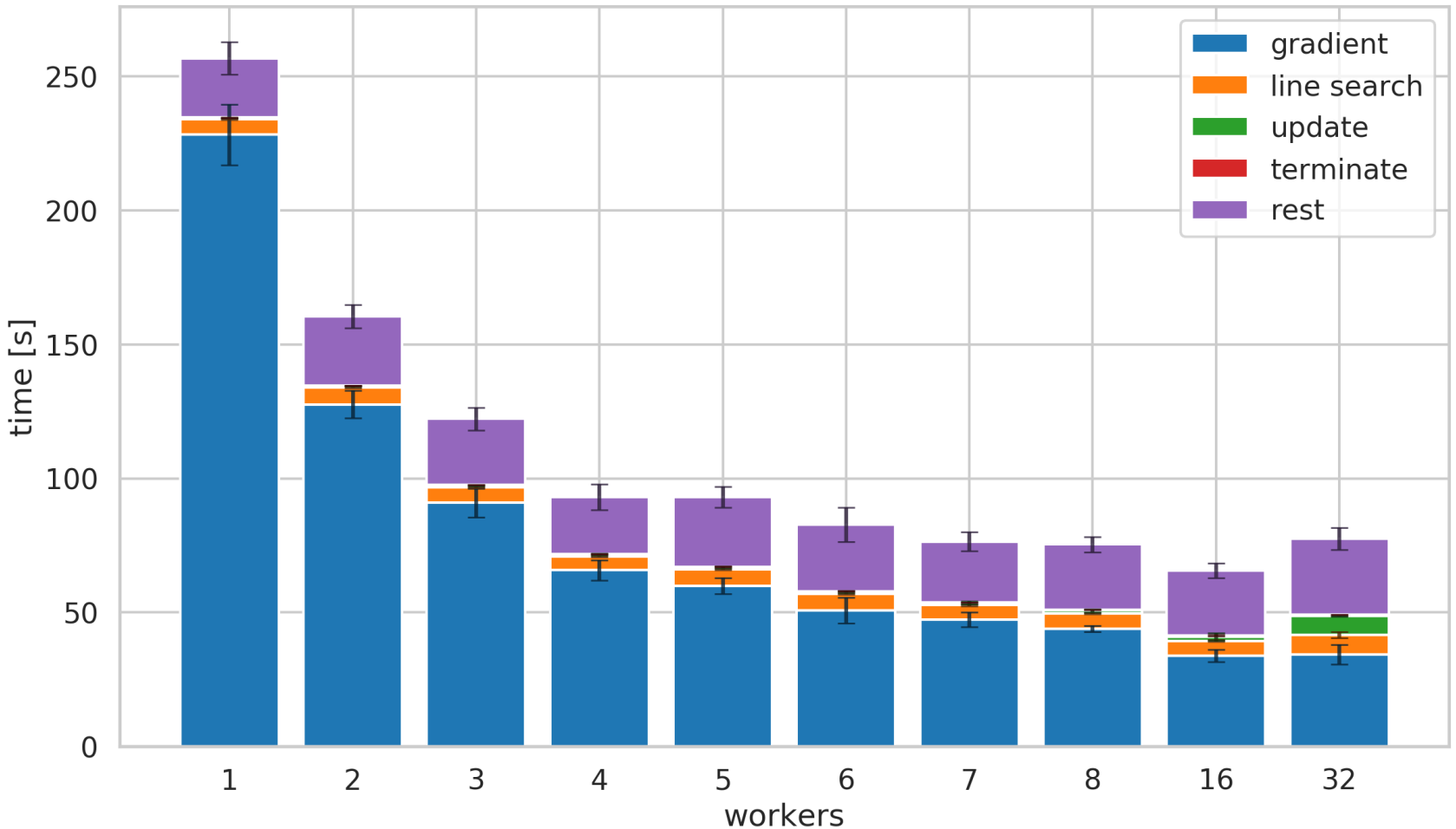

gradient
update
terminate
rest
time [s]
0
5
10
15
20
1
2
3
4
5
6
7
8
workers

Small model

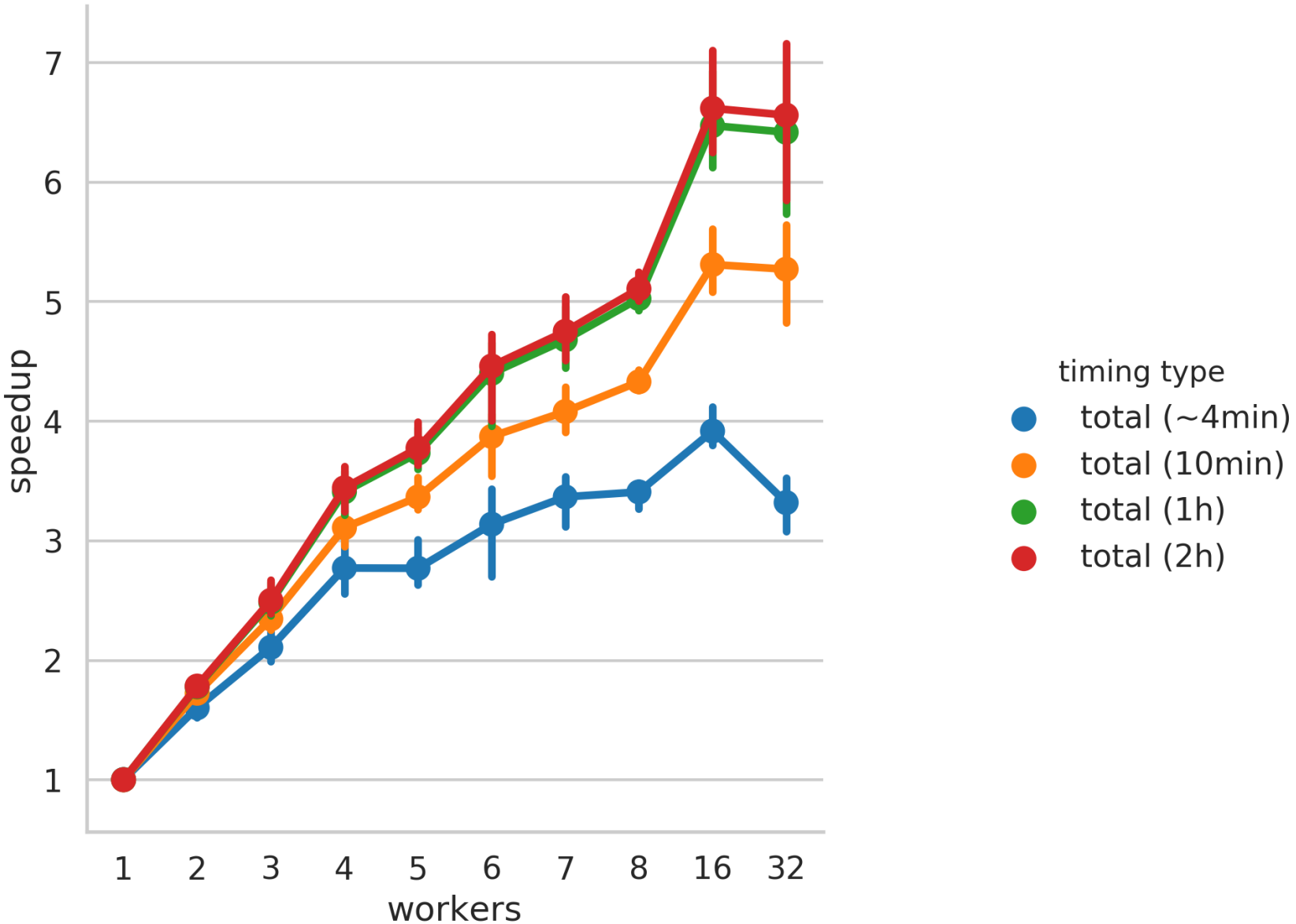


- update slow, but at least constant
  - fast model not "main target"
  - mainly want to speed up runs that take hours
  - this constant part becomes insignificant
- rest ignored for now, focusing on long runs

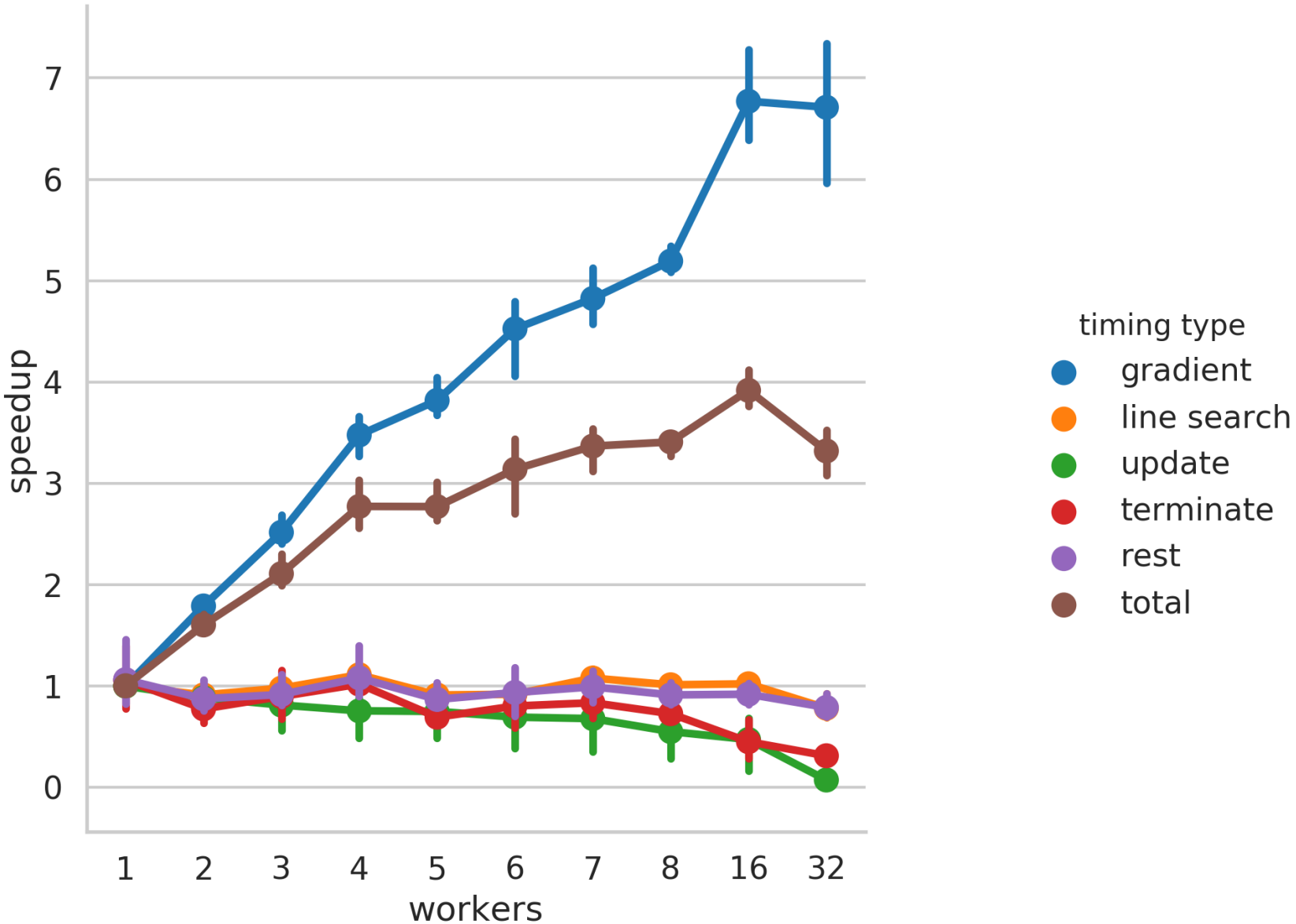
Big model


gradient
line search
update
terminate
rest
time [s]
0
50
100
150
200
250
1
2
3
4
5
6
7
8
16
32
workers

Big model

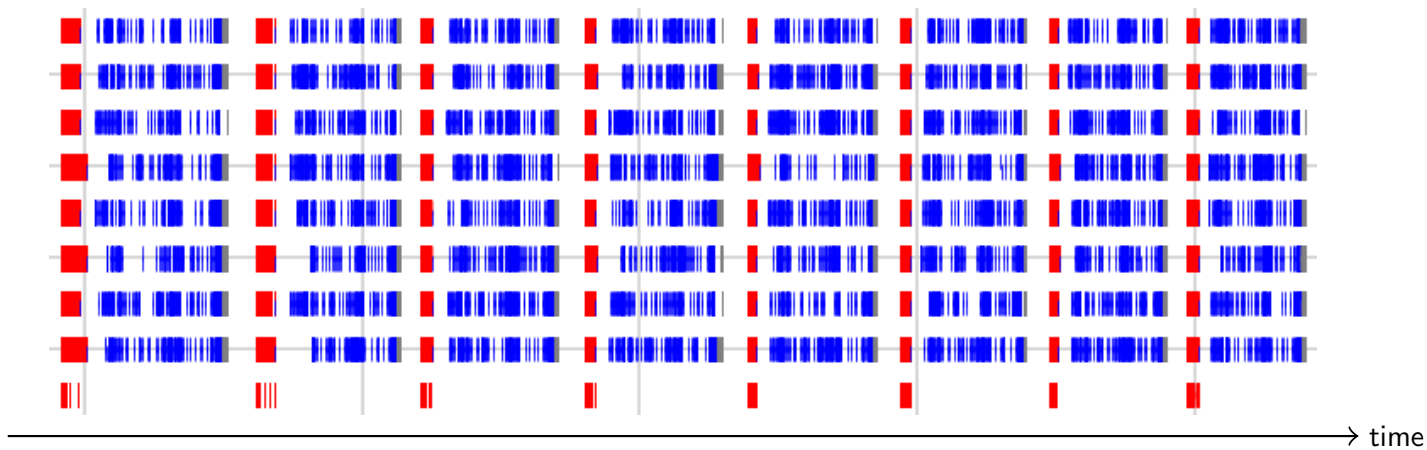

speedup
7
6
5
4
3
2
1
1
2
3
4
5
6
7
8
16
32
workers
timing type
total (~4min)
total (10min)
total (1h)
total (2h)

Big model


speedup
0
1
2
3
4
5
6
7
workers
1
2
3
4
5
6
7
8
16
32
timing type
gradient
line search
update
terminate
rest
total

Big model

- gradient not scaling well
  - mainly due to first partial derivative on each node taking long due to expensive precalculation



- big rest term caused by long synchronization step in serial part (master node) between roofit and minuit
- specifically the many constant terms in this model

Conclusions

- effective collaboration requires short wall times
  - minutes rather than hours
  - Parallelization can deliver this
- improved scaling of existing likelihood-level parallelization
- introduced new flexible framework
  - multi-level parallelization: likelihood, gradient
- gradient-level parallelization scales for large ($> 1\,\mathrm{h}$) fits
  - main goal achieved!

Related poster

Stephan Hageböck: *A faster, more accessible RooFit*

Outlook

- include new infrastructure into ROOT/RooFit
- for the adventurous: development version
  - **github.com/roofit-dev/root**
- investigate imperfect scaling observed in gradient calculation
- redesign core test statistic classes for future-proof interface
- allows to plug in any new types of calculation strategy
  - e.g. analytical derivatives
- `HESSE` can be parallelized in similar way
- With combination of all techniques expect speedups of factor 20 for fits > 1 hour.

What to expect in the future